Seismic External Stability of Geotextile Reinforced Walls

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ABSTRACT: A limit equilibrium analysis is used in this paper to determine the critical acceleration of a statically designed geotextile reinforced retaining walls. The wall is represented by a deck of playing cards. Each card represents a layer that can slide relative to the next layer. The results of this analysis show that the top layer is the critical layer and that the geotextile-soil interface friction value is the key controlling parameter in the determination of the external seismic stability. Tests conducted in a shake box on walls 0.95m wide x 2.05m long x 0.72m high gave results that are in agreement with the analytical results.

1 INTRODUCTION

The static design and stability considerations for reinforced earth retaining walls have been extensively studied (for example, Lee et al., 1973). In contrast, the results of only a few studies (Richardson and Lee,1975; Richardson et. al., 1977; Wolfe et al., 1978; Vrymoed, 1989; and Nakanshi and Sakaguchi, 1990) are available on the seismic stability of soil-reinforced and geotextile reinforced retaining walls.

The seismic external stability of geotextile reinforced walls is usually found by assuming that these walls behave as a rigid block with sliding occurring at the base of the wall as in static analysis (Christopher et al., 1990). In this paper, the external seismic stability of geotextile reinforced walls is determined using a deck of card analogy. The intention is to determine the acceleration that a statically designed geotextile reinforced walls can sustain before movement (displacement and/or rotation) occurs.

2 ANALYSIS

In this analysis, a geotextile reinforced earth wall is assumed to be similar to a deck of playing cards. Each card represents a layer that is rigid and can slide relative to the cards above and below it (Fig. 1). Further, it is assumed that the backfill is cohesionless with no permanent surcharge load, the spacing (S_v) and the total length (L) of the geotextile are constant. Under a uniform vertical acceleration, $a_v = k_v g$, and a uniform horizontal acceleration, $a_v = k_h g$, where k_v and k_h are the vertical and horizontal seismic coefficients respectively, and g is the acceleration due to earth's gravity, the disturbing force (F_D) for any individual layer i is

$$F_D = k_h W_i + (P_a)_i + (\Delta P_{aE})_i \tag{1}$$

where W is soil weight, P_a is the static lateral thrust given as

$$P_a = \frac{1}{2}\gamma_b(2i - 1)S_v^2 K_a \tag{2}$$

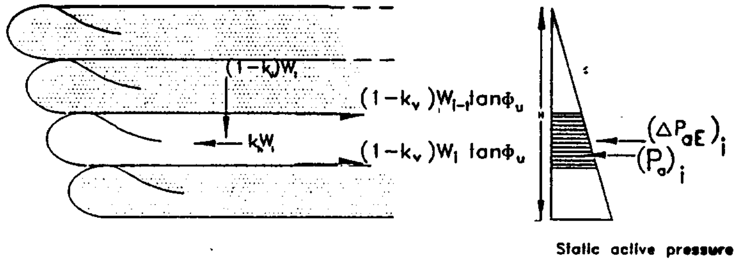

Fig. 1 Forces on layer i due to a seismic event.

and ΔP_{aE} is the increase in lateral thrust from a seismic event given as

$$\Delta P_{aE} = \frac{1}{2}\gamma_b(2i - 1)S_v^2\ \Delta K_{aE} \qquad (3)$$

and γ_b is the unit weight of the backfill, K_a is the static active earth pressure coefficient and ΔK_{aE} is the increase in active earth pressure coefficient from seismic loads. Seed and Whitman (1970) suggested that, for practical purposes, ΔK_{aE} can be taken as

$$\Delta K_{aE} \approx \frac{3}{4}k_h \qquad (4)$$

Substituting $W_i = i\gamma S_v L k_h$, equations (2), (3) and (4) into equation (1), the disturbing force to push any layer i relative to the layers above and below is,

$$F_D = i\gamma_f S_v L k_h + \frac{1}{2}(K_a + \frac{3}{4}k_h)\gamma_b S_v^2(2i - 1) \qquad (5)$$

The resisting force (F_R) consists of the interface frictional resistance of the top and bottom boundaries of layer i. Thus,

$$F_R = \gamma_f S_v L\ \tan\phi_u(1 - k_v)(2i - 1) \qquad (6)$$

where the γ_f denotes unit weight of soil in the geofabric wall and ϕ_u is the soil-geotextile interface friction angle. It is usual to relate ϕ_u to the angle of friction of the soil (ϕ) by $\phi_u = \alpha\phi$ where α is the adhesion factor. The seismic factor of safety against sliding is

$$F_{sE} = \frac{F_R}{F_D} \qquad (7)$$

which leads, by substituting equations (5) and (6) into equation (7), to

$$F_{sE} = \frac{(1 - k_v)\ \tan(\alpha\phi)\ (2i - 1)}{ik_h + \frac{1}{2}\frac{S_v}{L}(\frac{\gamma_b}{\gamma_f})(K_a + \frac{3}{4}k_h)(2i - 1)} \qquad (8)$$

From equation (8), the top layer, i = 1, has the lowest factor of safety and it is, therefore, the critical layer. The critical acceleration for sliding, k_{cs}, at the top layer occurs when $F_{sE} = 1$. Thus, from equation (8),

$$k_{cs} = \frac{(1 - k_v)\ \tan(\alpha\phi) - \frac{1}{2}\frac{S_v}{L}\frac{\gamma_b}{\gamma_f}K_a}{(1 + \frac{3}{8}\frac{S_v}{L}\frac{\gamma_b}{\gamma_f})} \qquad (9)$$

The critical acceleration for rotation, k_{hcr}, following the procedures above, is

$$k_{cr} = \frac{(1 - k_v)[\ \tan(\alpha\phi)\ (n - 1) + \frac{L}{2S_v}] - A}{(1 + \frac{3}{8}\frac{S_v}{L}\frac{\gamma_b}{\gamma_f})(n - \frac{1}{2})} \qquad (10)$$

where

$$A = \frac{1}{2}K_a\frac{S_v}{L}(\frac{\gamma_b}{\gamma_f})(n - \frac{2}{3})$$

and n is the number of layers. A plot of equations (9) and (10) showing the variation of α with k_{cs} and k_{cr} for $k_v = 0$ is shown in Fig. 2. The principal factor controlling seismic

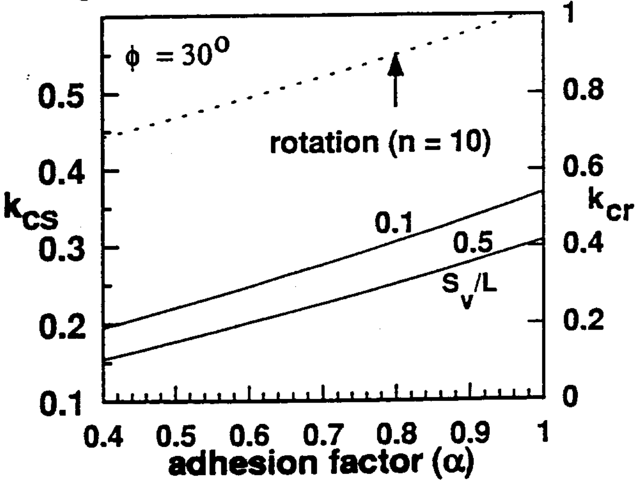

Fig. 2 Critical accelerations for sliding and rotation.

stability is the soil-geotextile interface adhesion factor. To mobilize the maximum seismic stability, the spacing to length ratio should be small, preferably less than 0.1. For a given wall, k_{cr} is usually much greater than k_{cs}.

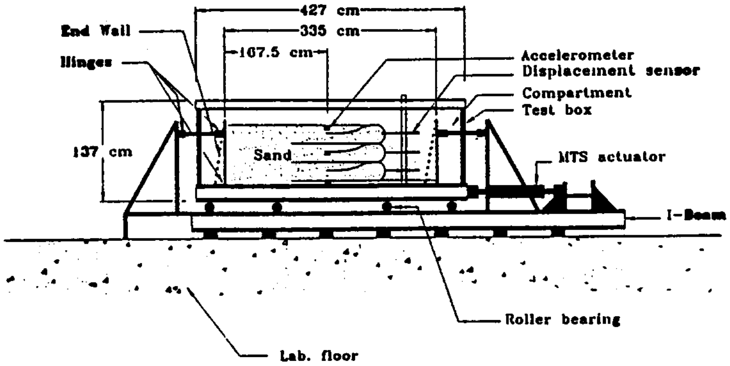

Fig. 3 Diagrammatic section of shake box

3 EXPERIMENTS

A series of tests was conducted on 0.95m wide x 2.05m long x 0.72m high geotextile reinforced walls in a shake box Fig. 3. The sand used was a dry silica sand with a mean diameter of 0.55mm, coefficient of uniformity of 2.4, minimum void ratio of 0.583 and maximum void ratio of 0.951. Tests were conducted at a relative density of 67% corresponding to an angle of friction of 41°. The geotextile used was a woven polypropylene fabric with physical properties reported by the manufacturer as follows:

Grab tensile strength: 136 kg
Grab tensile elongation: 20%
Wide width tensile strength: 35 kN/m
Wide width elongation: 15%/7% (warp/fill)

The protocol used for constructing the walls is similar to that suggested by Stewart et. al. (1977). The fabric length for all tests was kept constant at 1.33 m and the layer spacing was varied. The frequency for all tests was kept constant at 3 Hz. The walls were shaken initially at an acceleration of 0.05g for 30 cycles to smooth out any small irregularities (mainly on the face of the wall) during preparation. Horizontal accelerations were applied in increments of 0.05g for 30 to 50 cycles per increment.

Accelerometers were located at the bottom of the box (cemented in place), at mid-height and at the top of the walls. The accelerometers at the mid-height and at the top of the walls were mounted on 75mm x 75 mm x 25mm thick wooden plates and buried into the sand. Displacement sensors were positioned at the mid-height of each layer.

4 RESULTS AND DISCUSSION

It was observed, in all tests, that movement (sliding) commenced at the interface of the top and second layer. Later, at higher accelerations, each successive layer stated to slide. The critical acceleration in any test was determined at the initiation of sliding of the top layer. A typical result is shown in Fig. 4 and a summary of the test and analytical results is shown in Table 1.

The results did not show any consistent decreasing trend of critical acceleration with spacing to length ratio. However, the predicted critical acceleration is, in general, in good agreement with the test results.

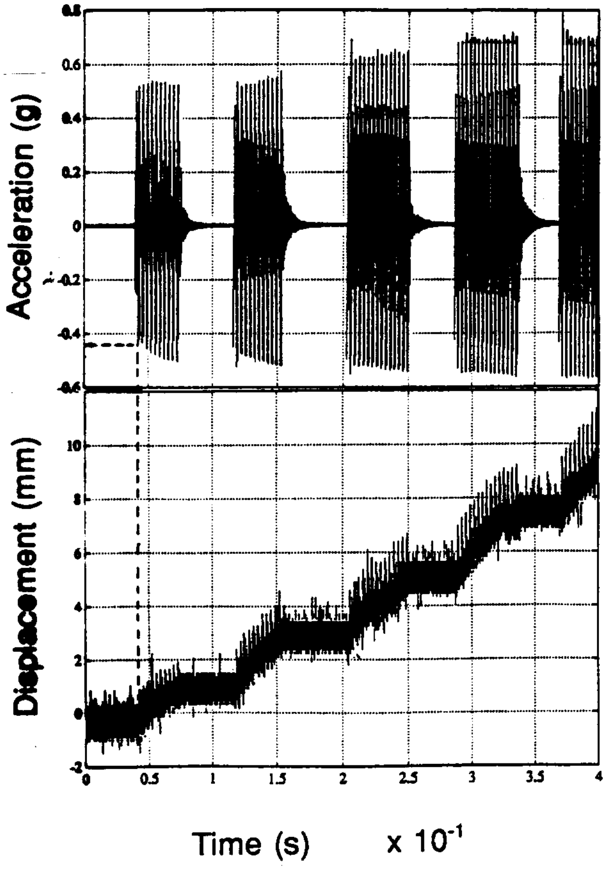

Fig. 4 Acceleration and displacement at the top layer for $S_v/L = 0.135$

Table 1. Critical accelerations observed and predicted.

S_v/L	k_{cs}^{*}	k_{cs}^{**}
0.135	0.45	0.43
0.18	0.55	0.42
0.27	0.45	0.40

* observed ** predicted for $\alpha = 0.6$

5 CONCLUSION

The main controlling factor in the seismic stability of geotextile reinforced walls is the geotextile-soil interface friction value. The critical acceleration, for most practical cases, is directly proportional to the geotextile-soil interface friction value. The spacing to length ratio does not have a significant effect on the external seismic stability. However, to maximize the seismic resistance, the spacing to length ratio should be kept small (about 0.1), at least in the top portion of the wall.

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